# Polarized H⁻ Jet Polarimeter For Absolute Proton Polarization Measurements in RHIC

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**Abstract.** Status of the H-jet polarimeter development is reviewed. A number of design issues are discussed including vacuum system, integration into the RHIC storage ring, scattering chamber, and uniform vertical holding field magnet design. The absolute proton polarization of the atomic hydrogen-jet target will be measured to 3% accuracy by a Breit- systematic error contribution to the jet-target polarization measurements is also discussed.

## INTRODUCTION

An absolute polarimeter is an essential tool for polarized proton acceleration and polarization studies at high-energy colliders. Elastic scattering in the Coulomb-nuclear interference region was proposed for the absolute polarization measurements in RHIC [1]. Particle identity provides a unique opportunity for absolute polarization measurements in elastic proton-proton scattering of the polarized proton beam on a polarized proton target. Since analyzing powers for scattering of the polarized beam on an unpolarized target and unpolarized beam on the polarized target are equal, the beam polarization can be directly expressed in terms of the target polarization value, which can be precisely measured by Breit-Rabi polarimeter [2]. The polarimeter target is a free atomic beam jet, which crosses the RHIC beam in the vertical direction. With a state-of-art atomic polarized source, the maximum H-jet target thickness of about 0.9 $10^{12}$ atoms/cm$^2$ can be achieved [3], which limits the polarimeter counting rate to less than 100 events/sec (a storage cell technique cannot be used, due to background considerations). Therefore, an integration time of about 10 hrs will be required for 2% statistical accuracy measurements [4]. These measurements will be used for calibration of a much faster p-Carbon CNI polarimeter, which is proven to be a very effective instrument for depolarization studies and polarization time-evolution monitoring during storage in RHIC [5].

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# POLARIZED H-JET POLARIMETER

## Polarimeter location

The H-jet polarimeter will be installed at the RHIC beams intersection IP-12. This intersection is presently not occupied, is close to the p-Carbon CNI polarimeter, and infrastructure is available, so minimal construction work is required. The drawbacks are the very limited available space and difficult access. The decisive factor for the choice of IP-12 was the least interference with the other experiments and RHIC equipment. Due to the very small H-jet target thickness ($\sim 10^{12}$ atoms/cm$^2$), the polarimeter can be operated continuously, without any effect on the RHIC beams, and the remote location excludes any background generation for the other experiments.

## Polarimeter vacuum system

The H-jet polarimeter includes three major parts: polarized Atomic Beam Source (ABS), scattering chamber, and Breit-Rabi polarimeter (see Fig.1). The polarimeter axis is vertical and the recoil protons are detected in the horizontal plane. The common vacuum system is assembled from nine identical vacuum chambers, which provide nine stages of differential pumping. The system building block is a cylindrical vacuum chamber 50 cm in diameter and 32 cm long with the four 20 cm (8.0") ID pumping ports.

## Vacuum pumps

Each chamber will be pumped by two VT1000HT –Varian oil-free turbomolecular pumps (TMP) with ceramic bearings. A third pump can be installed if necessary on some stages, but even if one of two pumps fails the polarimeter still can be operated with somewhat reduced target density. The "Macrotorr" model TMP features high $\sim 10^6$ compression ratio for $H_2$ pumping and 900 l/sec pumping speed. The TMP cable length can be extended to 60 m, which allows the power supplies to be located outside the RHIC tunnel. Oil-free, piston-type EcoDry-15 pumps (Leybold) will be used for TMP backing.

## Polarized atomic beam source

The ABS part of the polarimeter includes five vacuum chamber and five differential vacuum stages (see Fig.1). The ABS isolation valve is situated in the drift space between two groups of sextupole magnets, where space is available without any sacrifice in source performance. An isolation valve will be used for dissociator maintenance and it will be included in the interlock system to protect RHIC in case of a vacuum leak in the dissociator. With the hydrogen flow in the dissociator ~1-2 scc/sec, and $2 \cdot 900$ l/sec pumping speed, the vacuum is expected to be: 1-dissociator chamber $\sim 5 \cdot 10^{-4}$ mbar; 2– skimmer chamber $\sim 10^{-4}$ mbar; 3-sextupole magnet chamber

~$10^{-5}$ mbar; 4-drift space chamber ~$3\cdot10^{-6}$ mbar; 5- focusing sextupole, RF-transition chamber ~$5\cdot10^{-7}$ mbar, scattering chamber~$5\cdot10^{-8}$. In conventional dissociator design the nozzle is cooled to 30-100°K to produce a "cold"- (low velocity) atomic beam. The acceptance of the sextupole separating magnets is higher at lower beam velocity, and the polarized beam density (for the same beam intensity) is therefore higher too. The high-intensity polarized proton (or H- ion) ABS operating with the 30°K nozzle temperature, would produce atomic beams of ~$10^5$ cm/sec velocity and about $5\cdot10^{11}$ atoms/cm$^3$ atomic beam density in the ionizer region. A 30°K ABS is successfully implemented in the EDDA experiment at COSY with a polarized jet target [6].

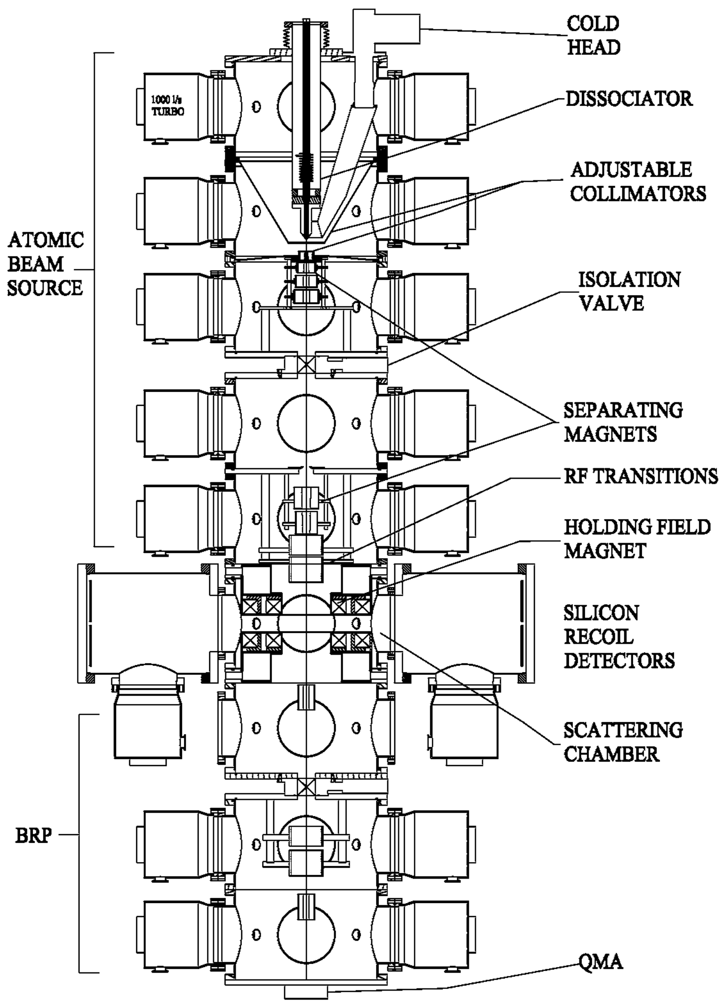


**Figure 1**: Polarized H-jet polarimeter assembly. BRP-Bret-Rabi polarimeter.

The $5 \cdot 10^{11}$ atoms/$cm^3$ atomic beam density was obtained with a lower beam flux and lower gas loading to the vacuum system than in the high flux ABS for storage cells feeding (HERMES, PINTEX, BLAST, ANKE), which operate at about 80ºK. However, reliable and reproducible long term operation is easier to sustain at 80ºK, and a somewhat higher atomic beam fraction (atomic/molecular beam ratio) was obtained at 80 ºK (due to the recombination minimum at this temperature). Therefore, in spite of the fact that beam density, not flux, is the figure of merit for the jet-target, the RHIC polarimeter atomic beam energy was chosen at ~80ºK. The sextupole separating magnet system was designed for an atomic beam velocity of about $2.0 \cdot 10^5$ cm/sec, which was measured for a dissociator nozzle temperature cooled to 80ºK. The separating magnet system calculations and optimization are presented in the T.Wise et al., paper in this conference.

The dissociator design is conventional at a 13.56 MHz frequency. The tuning procedure developed by H. Kolster [7] will be used for optimization of the RF power coupling. A cryocooler will have sufficient power (~100 W at 80˚K) to maintain the dissociator nozzle at the optimal temperature, which is expected to be in 60-80ºK range. The dissociator and the first skimmer positions are designed to be adjustable without breaking vacuum. This will allow fine-tuning of the nozzle-skimmer and skimmer-sextupole magnet gaps, which are critical for the optimal ABS performance. The 32 cm drift space chamber #4 can be replaced with a shorter 20 cm chamber to study the effect of the drift space length on the ABS performance.

## Scattering chamber

The CNI elastic p-p collision asymmetry is peaked at a momentum transfer of about $|t|$~0.001- 0.01 $GeV^2$, which corresponds to the recoil proton scattering angles 85-89 degrees for RHIC beam energies of 25-250 GeV/4/. The silicon strip recoil detectors are situated at 80cm distance from the jet-target in the recoil-arm cylindrical chambers, which are attached to the standard central chamber (see Fig.1). The pumping of the collision region is produced by the two 900 l/sec TMP's, backed by an additional TMP to ensure a high vacuum level with the mostly hydrogen residual gas composition. The scattering chamber will be bakeable with metal seals to keep the base pressure at $10^{-8}$ mbar level (without atomic beam, isolation valves are closed). The scattering angle is defined by the collision point within ~10 mm H-jet and the position sensitive silicon detector. The recoil proton energy is defined from silicon detectors and the time-of-flight is used to suppress the background. The scattering angle can be further constrained by remotely adjustable collimators located at ~4.0 cm distance from the target.

At the intersection point colliding bunches arrive at the same time and cannot be resolved by TOF. Therefore, the two beams will be separated spatially in the horizontal plane by about 10 mm, and the entire polarimeter apparatus can be scanned across the two beams in horizontal direction. In this way the scattering for one beam at a time can be selected in the polarimeter target, since the H-jet size is less than 10mm. To reduce the wake-field effect on the RHIC beams, the center part of the scattering chamber of 6 cm in diameter is enclosed in a metal grid screen. The grid screen has a sufficient vacuum conductance, and two 1.0cm openings for the recoil protons.

### Holding field magnet

The vertical direction of the target polarization in the collision region is defined by a 1.0-1.5 kG vertical magnetic produced by the holding field magnet (see Fig.1). The coils and magnetic steel plates of this magnet are enclosed in stainless steel casings which are sealed in-between standard vacuum chambers, so that high-current vacuum feed throughs are not required. The magnet design has to satisfy a number of requirements: a) sufficiently high field is required to produce high proton polarization of the atomic beam (at 1.0 kG the maximum proton polarization is 95% and at 1.5 kG –97.5%); b) magnetic field homogeneity better than $10^{-3}$ within ~4.0 cm center region is required to tune the holding field magnitude in-between the depolarizing resonances and avoid depolarization by the bunch wake-field induced transitions in the atomic beam; c) holding magnet steering effect to the recoil protons must be minimized by compensation coils, whose fields are adjusted to keep the total field integral along the proton path near zero. The RF-transition cavities, which produce the proton polarization in the atomic beam, are closely positioned to the magnet and must be shielded from the holding field by additional magnetic screens.

## TARGET POLARIZATION MEASUREMENTS

To achieve the polarimeter design accuracy of 5% for accelerated protons, the effective proton polarization of the target must be measured to at least 3% accuracy. According to the atomic beam transport calculations about 15% of the total $H^-$jet beam intensity will be within the BRP acceptance. The proton polarization of this beam part can be measured to ~1% accuracy by taking a set of atomic beam intensity measurements at different RF-transition settings. To derive the effective target proton polarization, as seen by the RHIC beams, from BRP measurements a number of systematic error contributions have to be determined with the high accuracy.

### Beam induced depolarization

The effect of bunched-beam induced resonance depolarization can be directly measured in the BRP. This depolarization is not uniform across the target cross-section because the accelerated beam size of ~ 1.0 mm in diameter is much smaller than the jet-target. The BRP measures just a fraction of atomic beam, and the correction error might be large even if depolarization is just a few percent. To avoid this problem, the plan is to suppress the depolarization resonances by tuning the strength of the holding field in-between the adjacent resonances. The resonance position as a function of the holding field value will be measured using the BRP. The success of this plan depends on the width of the depolarizing resonances, which in turn is defined by the holding field uniformity and stability. To ensure depolarization suppression below the 1% level is a difficult task. It is easier to achieve at 1.5kG field strength due to larger resonance separation.

## Target polarization dilution by molecular hydrogen and water vapor

The molecular hydrogen contamination of the atomic beam can be at the 5-10% level. The target polarization dilution by the molecular hydrogen (or water vapor) is the main systematic error contribution to the polarization measurements. Detailed studies of polarization dilution will be required to reduce the contamination to the lowest possible level and to develop techniques for precision correction measurements to meet the polarimeter accuracy design goal.

The contamination in the beam, which has passed the scattering chamber, can be measured in the first BRP chamber, before the sextupole magnets. The nondestructive beam diagnostics based on TOF measurements of the ion beams produced by electron beam ionizer can be used for on-line measurements. In off-line studies, a beam mass-analyzer can be installed in the scattering chamber and correlation with the dissociation ratio measurements (which will be monitored by another TOF mass-analyzer in the ABS) will be established, which will help to derive the polarization dilution correction factor.

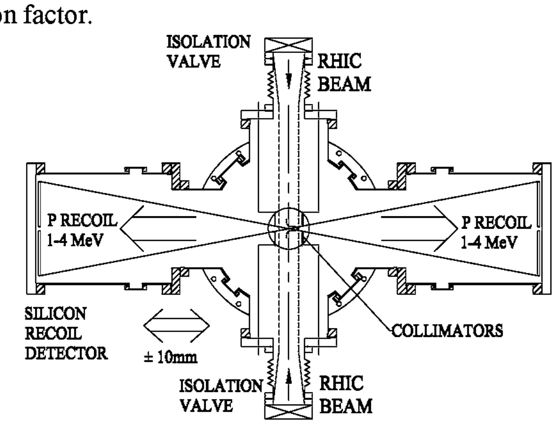


**Figure 2**. Scattering chamber.

## $H^-$ JET POLARIMETER INTEGRATION INTO THE RHIC

The polarimeter construction and tests will be done at the test facility in the linac injector complex. The polarimeter will be moved to the RHIC tunnel just before the polarized proton run and moved out for the further development to the test facility. The polarimeter is designed to be movable, i.e. it can be taken apart and reinstalled in either place in 2-3 days. The polarimeter will be removed from RHIC during the heavy-ion run, which relaxes the requirement to the polarimeter vacuum system (the polarimeter chambers cannot be baked because the permanent sextupole magnets do not tolerate heating above 50°C). At the test facility the polarimeter will be available for the precision polarization diagnostics development and systematic error studies of the jet-target polarization.

The polarimeter will be installed in RHIC between two isolation valves (see Fig.2). The isolation valves allow only a short part of the ring (about 1.0-1.5 m long) to be vented for polarimeter installation; therefore vacuum recovery time is reduced. These valves will also be included in the interlock system to protect the RHIC vacuum. In case of a leak in the polarimeter (most likely in dissociator) the vacuum sensors in the scattering chamber will trigger the close of the ABS and BRP isolation valves, if vacuum is improved RHIC operation can be continued without the polarimeter. Otherwise RHIC beams will be damped and the polarimeter isolation valves will be closed.

The first H-jet polarimeter operation in RHIC is planned for the 2003-2004 polarized run. The goals for the first run will be obtaining reliable operation at the designed intensity and high (over 80%) atomic beam polarization. The atomic beam polarization measurement accuracy might be at +/-5% level. It will require another one or two years to achieve the absolute accuracy of +/-2% for measurements of effective jet-target polarization.

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